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Training Dismounted Soldiers in Virtual Environments: Enhancing Configuration Learning

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For nearly a decade the U. S. Army Research Institute for the Behavioral and Social Sciences (ARI) has conducted research in using virtual environments (VE) to train dismounted soldiers. While showing that some dismounted soldiers skills can be trained in VE, the research has also identified problems in using VE for soldier training. Spatial performance deficiencies caused by disorientation and perceptual distortion have been found. This paper describes research investigating the effectiveness of various VE navigation aids in overcoming inherent VE deficiencies, thereby enhancing VE spatial learning.

Sixty-four participants received a guided tour of the third floor of a virtual building, freely explored the environment visiting six named destinations along the way, and then practiced finding each destination in turn. After training, participants were asked to estimate the distance and direction to destinations not in their line of sight, to locate each destination by traveling to it after having been teleported to another destination, and to place room cut-outs on a map outline of the third floor. The only navigation aid that improved performance on these tasks was providing an aerial view of the VE. The effectiveness of the aerial view depended on how the participants used it.

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Personnel Performance and Training Technology

FOREWORD

The U. S. Army has made a substantial commitment to virtual training systems for use in distributed computer networks and to the electronic battlefield for combat training. The current generation distributed training system, the Close Combat Tactical Trainer (CCTT), provides realistic combat simulation for soldiers fighting from vehicles, but not for individual dismounted soldiers. Virtual Environment (VE) technology provides a potential mechanism for including dismounted soldiers in the simulated battlespace. The U.S. Army Research Institute (ARI) for the Behavioral and Social Sciences, with contract support from the University of Central Florida Institute for Simulation and Training, has conducted a research program to investigate the use of VE for training dismounted soldiers.

This report describes experiments designed to explore the potential of VE for training dismounted soldiers. The research employs a highly detailed computer model of a large office building to determine if visual immersion in a virtual world improves performance on tests of configuration knowledge. It discusses the usefulness of VE navigation aids in acquiring spatial knowledge, and identifies the conditions under which they are effective. Information is also presented on retention of spatial knowledge acquired in a VE.

The ARI Simulator Systems Research Unit conducts research to improve the effectiveness of training simulators and simulations. The work described is part of ARI research task 202a, Virtual Environments Research for Infantry Training and Simulation. This research has been briefed at the NATO Human Factors and Medicine Panel Workshop in the Hague and has been submitted as a paper for presentation at the Army Science Conference.

Zita M. Simutis

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Technical Director

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This research represents the efforts of many talented and creative people. I would like to thank Ms. Kimberly Parsons who directed the development of the virtual environment, Mr. Chris Kachurak, who modeled the environment, and Mr. Jason Daly, who not only developed much of the software, but also kept the hardware and software up and running throughout the research project. Thanks also go to Mr. Glenn Martin who developed a very nice operator interface for running the experiment and to Mr. Greg Shumaker who developed the audio subsystem. Thanks to Mr. Jim Parsons who developed parts of the user interface. We would like to thank all of the research consortium fellows who spent countless hours assisting in the data collection to include Mr. Bob Allen, Ms. Mar Rodriguez, Mr. Jason Kring, and Ms. Amy Bolton. Thanks also to Mr. Jeff Stahl who helped collect data and scored some of the configuration knowledge tests. Finally, I would like to thank all the research participants. Without their participation, the research would not have been possible.

TRAINING DISMOUNTED SOLDIERS IN VIRTUAL ENVIRONMENTS: ENHANCING CONFIGURATION LEARNING

EXECUTIVE SUMMARY

Research Requirement:

The U. S. Army continues to look for better and cheaper ways to train their dismounted soldiers. Networked virtual training systems provide excellent training for soldiers training from vehicles, but have been less successful in providing dismounted soldier training. Although virtual environments (VEs) can potentially fill the need for including dismounted soldiers in the simulated battlespace, deficiencies in current VE technology can reduce their training utility. At the same time, VEs have unique characteristics that, if used wisely, can increase both the efficiency and effectiveness of training our dismounted soldiers.

Procedure:

A computer model of one floor of a large office building, used in previous research (Bailey & Witmer, 1994; Witmer et al., 1996) was adapted for this experiment. All passageways in the virtual building were widened to reduce collisions, and additional rooms were modeled to increase the complexity of the layout. Separate VE models were constructed to represent the standard and the enhanced environments. The enhanced environment model was created by adding theme objects and sounds to the standard environment model. The models were created using Multigen II software and rendered by a Silicon Graphics Onyx with eight 200MHz processors and three RealityEngine2 Graphics Pipes. Both models were displayed using a Virtual Research V8 Helmet-Mounted Display (HMD).

The participants were sixty-four college students (novices) who had no previous exposure to the building. For data comparison purposes, a separate group of eight experts who had multiple exposures to the building was also used. Following a brief train-up, the novices were randomly assigned to one of eight treatment groups, who received different levels of navigation aids. Depending on group assignment, a participant experienced either the standard or enhanced VE, received orientation cues or did not, and could choose to view the VE from an aerial perspective or was restricted to viewing the VE from the normal perspective. Knowledge of the building configuration was tested by asking participants to take the shortest route between designated rooms, estimate the distance and direction to locations not in the line-of-sight, and to place room cutouts in their correct locations on a map. The navigation aids were not provided during the testing phase. A follow-up room placement test was given one week after the initial test to examine retention of configuration knowledge.

Findings:

The purpose of the navigation aids was to offset VE deficiencies that can interfere with the acquisition of configuration knowledge in a VE. The orientation cues had no significant effects on the acquisition of configuration knowledge. Participants receiving the enhanced environment performed better during training than those who received the standard environment, but not on the tests of configuration knowledge. Only the participants who received an aerial perspective view performed significantly better both during training and on the configuration knowledge tests. Participants with an aerial view during training also performed better on the one-week retention test.

The effectiveness of the navigation aids, including the aerial view, seemed to depend on how the participants used the aids. When the aids were used as a crutch to find a room quickly, they were not effective. Similarly, in those cases where the navigation aids increased the workload beyond what the participants could handle, no performance gains were realized. The navigation aids seemed to work best when participants were able to use them to organize or structure the environment. In general, more variance on the configuration knowledge tests was attributable to individual differences in spatial ability and interface proficiency than was attributable to the navigation aids. This finding underscores the necessity of measuring or controlling these individual factors when assessing the effects of navigation aids or other variables on spatial knowledge acquisition.

Utilization of Findings:

This research shows that the right VE navigation aids used in the right way can significantly improve configuration knowledge. Specifically providing an aerial view in the context of learning the layout of a building increases knowledge acquisition and retention of the building layout. Hence, in military applications where knowledge of interior spaces is important (e.g., hostage rescue, mission operations in urban terrain) providing navigation aids can enhance learning and retention. If navigation aids are to be effective, however, learners must be monitored to ensure they are using the navigation aids to organize the environment, rather than using them as a crutch, and to ensure that the navigation aids do not overload their attention capacity.

By identifying the types of individual skills and abilities that are important for learning spatial skills in a VE, this research provides a way that trainers and system developers can identify which soldiers can gain the most from VE spatial skill training. The results will be applied to the design of prototype mission planning and rehearsal systems.

TRAINING DISMOUNTED SOLDIERS IN VIRTUAL ENVIRONMENTS: ENHANCING CONFIGURATION LEARNING

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Training Dismounted Soldiers in Virtual Environments: Enhancing Configuration Learning

For several years, the U. S. Army Research Institute (ARI) for the Behavioral and Social Sciences has conducted a research program investigating the utility of virtual environments (VEs) for training skills needed by dismounted soldiers. Knerr et al. (1998) summarized much of that work along with lessons learned and training recommendations in a recent report. In the process of conducting the research, ARI researchers have identified deficiencies in VE technology that can adversely affect its utility for training soldiers. When training in VEs, soldiers might experience simulator sickness, become lost or disoriented, and manifest perceptual distortions. Although these deficiencies may reduce training effectiveness, VEs also possess unique characteristics that make them more flexible and which may enhance training effectiveness. Most VE training research has concentrated on making VE training as similar to real world training as possible. Almost no work has been done exploiting the unique characteristics of VE.

The purpose of this research is to enhance the acquisition of configuration knowledge by using the unique training opportunities provided by a VE. A VE has advantages over alternate learning methods (e.g., 2-D maps, verbal directions). Unlike maps, VEs require no mental transformations of 2-D images to 3-D representations, nor do VEs require transformation of verbal directions into an imagined mental model of the spatial layout. Immersive VEs provide realistic 3-D images of pathways and landmarks, which represent a more accurate, and perhaps, more easily retained mental image of the spatial layout. VEs permit viewing from multiple perspectives and can be easily augmented with features that enhance learning. This research investigates cognitive and perceptual variables thought to influence the speed and overall quality of spatial knowledge acquisition by using the unique possibilities provided by an immersive VE.

Spatial Knowledge Acquisition

Much research has been done in order to understand how humans and animals acquire information about the spaces that surround them and how they are able to find their way through complex environments. It has been more than 50 years since Tolman (1948) first suggested that his rats were using tentative cognitive maps indicating routes and paths to a goal location. While controversial at the time, Tolman's idea that a cognitive map guides spatial behavior has come to be widely accepted. Lynch (1960) investigated how people acquire knowledge of cities and the features of cities that helped people acquire this knowledge. Lynch found that people noticed five categories of features that helped them structure their environment: districts, landmarks, nodes, paths, and edges. Predating Lynch, Levine (1951) suggested that as people move through space they divide it into regions, paths, and barriers because space, in a philosophical sense, is empty and needs bounding and identification. The distinction between paths and bounded regions forms the basis for two different types of spatial knowledge, route knowledge and configuration knowledge.

Aspects of Spatial Knowledge

Siegel and White (1975) suggest a distinction between procedural descriptions and configuration knowledge. “Procedural descriptions” refer to knowledge acquired about the routes between locations. Such knowledge derived from maps, verbal or written directions, or navigation through the environment encodes a sequential record of the space between the start point, landmarks along the route, and the destination. “Configuration knowledge” refers to an awareness of the environment’s topographic properties (i.e., the general shape and arrangement of a surface). People initially acquire landmark knowledge, then route knowledge, and finally obtain configuration knowledge.

Landmark knowledge is the initial, and most critical, stage of configuration learning. Landmark knowledge, through the memorization and recall of distinctive features, enables and facilitates route knowledge. It would be incorrect to assume, however, that visual recognition of landmarks and recall of distinctive perceptual features constitutes complete landmark knowledge. The ability to discriminate one landmark from another and to attach a verbal label or name to the landmark represents a more advanced stage of landmark knowledge.

Route knowledge is achieved when people have enough landmark and spatial knowledge to traverse from a start point to a determined destination. To clarify this, Goldin and Thorndyke (1981) imply that route knowledge represents distances, orientation cues, and landmark sequence along a route. Route knowledge may also be thought of as a set of stimulus-response pairs or condition-action rules (Waller, 1999). In its earliest stages route knowledge only requires recognizing landmarks and familiar pathways. In its more advanced stages, travelers should recall which landmarks are along the route and their sequence. They may even reach the point where they become less dependent on the landmarks and have the route memorized as a series of route segment distances and turns.

Configuration knowledge is the most comprehensive form of spatial knowledge. Configuration knowledge is considered present when: a) the entire spatial layout is memorized allowing for calculation of distances between landmarks and destinations (euclidean and route); b) directions to destinations can be indicated accurately; and c) shortcuts can be engineered. As a person acquires configuration knowledge of an environment, a cognitive map or similar representation develops and is embedded in long-term memory (Golledge, 1987). This allows the use of mental imagery to determine direction to designated locations, estimate distances and determine appropriate routes. Unlike route knowledge in which learners need only recognize landmarks and directions along the route, configuration knowledge requires specific recall of the distance and direction to places throughout the spatial configuration.

Methods of Acquiring Spatial Knowledge

Generally, spatial knowledge is learned from maps or from navigation of the environment. Maps such as floorplans, blueprints, and "you-are-here" maps are

commonly used representations that provide a vertical or exocentric perspective. The exocentric perspective depicts the environment from the outside looking in. Navigating an environment provides a horizontal view from within the environment, that is, an egocentric perspective. Navigation can be either active or passive. Active navigation involves controlling one's own movement through the environment, including the speed, direction, and route of navigation. Passive navigation involves moving someone along a designated route and giving them no control of their speed or direction of movement.

Thorndyke and Hayes-Roth (1982) found that navigation through an environment is the best way to obtain knowledge of the routes and landmarks. Although configuration knowledge is better acquired initially through map study, knowledge acquired via a map does not retain its advantage over time. With extensive navigation in and exposure to the environment, the performance superiority of map learning diminishes to the point that navigation-trained performance typically exceeds map-trained performance. However, if rapid acquisition of configuration knowledge is desired, then a map or map-like representation may be preferred.

Measuring Configuration Knowledge

The traditional way to measure configuration knowledge is to require learners to sketch a map of the area (Lynch, 1960; Appleyard, 1970). Although map sketches have high face validity and clearly demonstrate knowledge acquisition, sketches are difficult to score, and may underestimate how much knowledge has been acquired. Wickens and Prevett (1995) used a variation of the map sketching task, asking participants to arrange paper cutouts of the objects in an environment on a piece of paper in the same configuration that they had appeared in the previously experienced environment. This map reconstruction task has the high face validity of the map-sketching task, yet is easier to score. Wickens and Prevett (1995) scored the map reconstruction task by measuring the linear distance from each participant's placement of a terrain feature to actual locations of the terrain feature in the environment. The map reconstruction task seems to have originated with Sherman, Croxton, and Giovanatto (1979), who required participants to construct a map by arranging landmark magnets on a blank board. Baird and Wagner (1983), using a similar procedure, asked students to move pieces labeled with building names around a board to represent the spatial relations between buildings on campus. More recently, Waller (1999) successfully used a map reconstruction (or map placement) task to measure configuration knowledge. Waller, however, used a scoring procedure that differed from that used by Wickens and Prevett (1995).

Another method, the projective convergence technique (Siegel, 1981), requires that participants estimate the bearing and distance to landmarks obscured from view from three different sighting locations. The end points of lines representing the bearing and distance estimates form a triangle from which several measures can be derived. These measures include accuracy, consistency, and miss distance. Accuracy is the distance between the centroid of the triangle and the target, while consistency is the perimeter of the triangle. Miss distance, another accuracy measure, is the sum of the distance from the vertices of the triangle to the target. Additional measures that can be used with the

projective convergence technique include heading error, distance error, and correlations between true and estimated distances. Heading error is the absolute value of the angular difference between the estimated direction and the true target direction. Distance error is the absolute value of the difference between the estimated and true target distances.

Correlations among projective convergence measures are typically high (Bailey, 1994; Witmer, Bailey, & Knerr, 1995; Waller, 1999). Hence there is no need to use all of the derived measures. While Waller (1999) suggested that consistency is relatively uncorrelated (average r of about .20) with other measures, Witmer et al. (1995) obtained a .79 correlation of consistency with distance error and Bailey (1994) found significant correlations of .74 and .38 with distance error in paper-based and computer-based projective convergence tests.

Another method requires that participants not merely know the layout, but also be able to apply that knowledge by following the most direct route between two designated landmarks or destinations (Witmer, Bailey, & Knerr, 1995; Satalich, 1995). The most direct route test involves routes that have not been specifically trained and which may never have been previously traversed. Siegel and White (1975) suggested that configuration knowledge might be a necessary condition for the invention of new routes.

Acquiring Configuration Knowledge in VEs

Witmer, Bailey, Knerr, & Parsons (1996) investigated the acquisition of spatial knowledge in a VE and the transfer of that knowledge from the VE to the real world. Using a model of a complex office building, Witmer et al. (1996) demonstrated that route knowledge acquired in a VE readily transferred to the real world. However, there was little evidence that configuration knowledge (i.e., general knowledge of the building layout) was acquired, and no evidence of transfer to the real world. Witmer et al. (1996) suggested that configuration knowledge might not have been acquired because no special effort was made to train that knowledge directly; rather it was expected that configuration knowledge would be acquired incidentally while learning the route. Although, participants were provided with a map indicating the route during the initial 15-minute training phase, instructions directed participants to study and learn the route, not the layout. In addition to the lack of specific configuration knowledge training, Witmer et al. (1996) also identified problems associated with the VE that may have interfered with learning the configuration; among these are a reduced field-of-view (FOV), disorientation following collisions with virtual walls, and simulator sickness.

Contrary to expectations, Witmer et al. (1996) found that map study had no effects on the acquisition of route or configuration knowledge in the VE. Satalich (1995), on the other hand, found that a control group receiving only a map outperformed groups who had direct exposure to the VE on a variety of measures of route and configuration knowledge. Although the VE modeled for Satalich's study was by no means simple, consisting of 39 separate rooms and over 500 objects, Satalich indicated that it was organized in a fashion to enhance configuration learning.

More recently, researchers studying configuration knowledge acquisition have demonstrated that configuration knowledge can be acquired using VEs. Ruddle, Payne, & Jones (1997), for example, demonstrated increased building configuration knowledge after nine unguided sessions in a VE. However, egocentric distance estimates to selected target locations were much poorer in the VE than in a previous similar study using the real building. Ruddle et al. (1997) also showed that including memorable landmarks improved route knowledge but had no effect on configuration knowledge. Wilson, Foreman, & Tlauka (1997) showed that participants trained to locate objects in a virtual building were more accurate in pointing to these objects in a virtual or real world test situation than were control group participants, who had no previous exposure to the virtual building. Wilson et al. (1997) also found that participants who trained in a virtual building outperformed the control group in drawing the layout of the building, but did not differ from participants trained in the real building. Wilson et al. (1997) attributed their success in demonstrating transfer of configuration knowledge from VE to the real world to using a simpler building layout than was used by Witmer et al. (1996). Collie & Reid (1998), using a 3-room building, showed that the layout of objects within a destination room was learned more quickly than was the layout of the rooms relative to each other. After a single learning trial, participants pointed more accurately to the location of objects within a room than to objects located in different rooms. Koh, Wiegand, Garnett, & Durlach (1999) using a relatively simple building layout demonstrated that configuration knowledge acquired in a virtual building transferred to the real world and was comparable to the same knowledge acquired in the actual building. Gillner and Mallot (1997) showed that configuration knowledge as represented by drawings of the perceived layout could be acquired in a VE. The layout to be learned in their study was relatively simple, however, consisting of repeating Y-shaped junctions (with 3 landmarks unique to each) linked together by the extension of one leg of the Y. Gillner and Mallot's work demonstrated that simple configurations could be acquired in a VE in a reasonable time without the use of maps or map-like representations.

There are inherent advantages for training configuration learning in an immersive VE. These include: four-dimensional representations of the environment (including time), ease of adding visual and auditory enhancements to aid learning, the ability to have multiple perspectives and modes of locomotion, and access to learning environments that may be otherwise unavailable for a variety of reasons. With VE there are fewer constraints on training access, real world hazardous environments can be represented without endangering personnel, and soldiers develop the confidence and familiarity that comes from the sense of being "present" in the environment without having to travel to distant real world sites for training. VEs can be indispensable for rehearsing military missions, particularly those involving search and rescue, or other operations in unfamiliar territory or hostile environments.

Designing Spaces that Enhance Spatial Knowledge Acquisition

Lynch (1960) identified design elements of urban spaces that people used to define and organize those spaces. He found regularities in the types of environmental features that were most often noticed, and hence most likely to be remembered. Lynch

identified five categories that encompassed these noticeable features: paths, edges or boundaries, districts (identifiable sections), nodes (intersections or focal points), and landmarks. An edge is a visible boundary, such as a river or a wall or any other environmental feature that creates a psychological boundary. Nodes are strategic spots in a city into which people can enter and are often the points to and from which they are traveling. Lynch found that landmarks that contrast with their surroundings and landmarks that could be seen from many different locations were more frequently noticed. Landmarks at path junctions or at nodes were also more often noticed. Landmarks that have directional information associated with them were reported to help people orient themselves. Darken and Sibert (1996) have combined some lessons learned from the work of Lynch and others and developed the following organizational principles for supporting wayfinding tasks in VE and in the real world:

1. Divide the larger environment into smaller identifiable parts (or districts) to preserve a sense of place.
2. Organize the small parts under a simple organizational principle, such as a grid or other logical spatial ordering.
3. Provide frequent directional cues (e.g., directional landmarks) to maintain orientation in the environment and preclude the wayfinder from becoming disoriented.

According to Rapoport (1977) orientation concerns three questions: (1) where one is; (2) how to get to where one is going; and (3) how one knows when one has arrived. To maintain orientation wayfinders must know their location and direction of travel relative to the larger environment. Knowing the spatial relationships between identifiable elements of the environment such as those described by Lynch (1960) may also be important to maintaining one's orientation.

In an exploratory study, Darken and Sibert (1993) investigated the use of various navigation aids (e.g., virtual sun, breadcrumbs, flying) in locating a target during VE exploration and in returning "home" to the start point. Although they presented no quantitative data, they reported that the navigation aids exerted a strong influence on navigation strategies, and that some of the aids clearly improved the efficiency of search and homing performance. For the most part, the relative effectiveness of these aids used singly and in combination for training configuration knowledge in VEs has not been determined. Darken and Sibert (1996) used a radial grid structure to divide the VE into recognizable segments and anchored these grid structures with posts, which were used as "compass points" to maintain orientation in the VE. They were able to show that a radial grid structure, when used either singly or in conjunction with a map, improved the accuracy of map sketches as compared to map-only and control conditions. Among the VE navigation aids initially investigated by Darken and Sibert (1993), the following seem promising and are further investigated in our current research: use of a virtual sun to maintain orientation, providing an aerial view, and dividing the VE into districts.

Darken and Sibert (1993) found that the inclusion of a single fixed feature (e.g., a virtual sun) which could be seen from any vantage point within the environment

improved performance on a search task in a VE by providing directional information throughout the environment, rather than being localized to a specific region. In the present study, a similar device (i.e., a virtual flagpole) served as a global reference point for orienting within the VE during the training phase.

Witmer, et al. (1996) reported that collisions with walls in the VE and the subsequent disorientation might have interfered with the acquisition of spatial knowledge. To reduce these effects, the VE was modified to reduce collisions (hallways and doorways were widened) and a local orienting aid was provided. The local orienting aid consists of an arrow projecting from the chest of the participant's avatar indicating the current direction of travel. This device reduces collisions by allowing participants to know their precise heading relative to objects in the VE, irrespective of head movement.

As first discussed by Lynch (1960) and reiterated by Darken and Sibert (1996), we divided the VE into distinct districts or quadrants to promote spatial knowledge acquisition. Each quadrant was populated with virtual objects representing a particular theme. Quadrants had different themes to enable participants to easily recognize and remember the quadrants. Both sights and sounds were added to represent the themes. While a quadrant's theme was apparent throughout the quadrant, the most salient themed landmarks were reserved for destination rooms, so that these rooms were readily associated with their quadrant. To ensure that participants associated the themed landmarks with the destination rooms, participants were forced to interact with these landmarks by identifying the theme represented. A similar technique was shown to increase recall of landmark location in a previous study (Guest, Bliss, and Lohmeier, 1997). Guest and Sadowski (1997) also found that strong visual attention directed at landmarks during training resulted in improved subsequent landmark recall.

As a final enhancement, some participants in this research viewed the environment from a vantage point well above the environment, and then return to a normal viewing perspective. This bird's-eye view affords the wayfinder a map-like view of the entire environment at the maximum height or some portion of the environment at lesser viewing heights. At the lesser heights an aerial view, in contrast to most maps, allows direct viewing of landmarks. While the value of using maps for acquiring spatial knowledge in VEs has been well documented (Satalich, 1995; Darken & Sibert, 1996; Bliss, Tidwell, & Guest, 1997; Miller, Clawson, & Sebrechts, 1999), the effects on spatial learning of using a bird's-eye perspective for viewing virtual spaces has rarely been investigated. Darken and Sibert (1993) have shown that providing a bird's-eye view of an outside environment where the navigator can look down on the entire environment can serve as an aid to efficient navigation. In a subsequent experiment, Darken and Sibert (1996) restricted the viewing height in order to prohibit the use of this navigational aid. However, a bird's-eye view should enhance the acquisition of spatial knowledge in a VE even in those cases where the entire environment is not visible at the same time. More recently Koh, et al. (1999) employed a virtual miniature 3-D model of one floor of a building displayed as an aerial view that could be manipulated using a mouse and a monitor. They showed that this model was as good as a VE or a real world environment for acquiring building configuration knowledge.

It should be noted that the type of VE enhancements that we used would be impractical or impossible to implement in an existing real world interior environment. A bird's-eye view of interior spaces requires removing the ceiling, as does the inclusion of a virtual flagpole. The local orientation device, while possible in the real world, is not needed in that environment because real world collisions are rare. The themed quadrants that were superimposed on the basic VE would be extremely difficult to implement in the real world, even if practical considerations did not completely rule out such disruptive alterations of the real environment.

The enhancements to the basic VE examined in this research decrease training realism. The enhanced VE is less similar to the real world environments than is a VE that has not been enhanced. By adding enhancements to the VE, we have purposely reduced its fidelity, but the enhancements also allow participants to more easily structure the VE for increased memorability and recall of the layout. Our approach is contrary to the common sense approach that requires the VE to be as similar as possible to the real world environment. Deficiencies in current VEs, however, preclude them from closely approaching reality. Therefore, extraordinary measures may be needed to compensate for these deficiencies, even if they involve a further departure from real world environments.

Experiment 1: Navigation Aids

Method

Participants. Thirty-two men and thirty-two women attending a local university participated in this research. The participants ranged from 18 to 47 years of age; the mean age was 23.08 years. Forty-four of these participants had no previous VE experience. All participants had normal vision uncorrected or corrected with contact lenses or glasses. Participants were screened for any history of seizures or other physical problems that would preclude their participation in this research. They received either cash payment or class extra-credit for participating in the research.

Equipment and Materials. A computer model of one floor of a large office building, used in previous research (Bailey & Witmer, 1994; Witmer et al., 1996) was adapted for this experiment. The 64-room VE model, 140 m. in length and 40 m. in width, encompassed approximately 4088 square meters and was created using over 35,000 polygons. A diagram of the layout of the model is shown in Figure 1. All passageways in the virtual building were widened to reduce collisions, and additional rooms were modeled to increase the complexity of the layout. Separate VE models were constructed to represent the standard and the enhanced environments. The enhanced environment model was created by adding theme objects and sounds to the standard environment model.

The VEs were modeled by Multigen II software and rendered by a Silicon Graphics Onyx with eight 200MHz processors and three RealityEngine2 Graphics Pipes. Both models were displayed using a Virtual Research V8 Helmet-Mounted Display (HMD). The V8 provides a color, high-resolution (640 (x3) x 480) 3-D view of the VE,

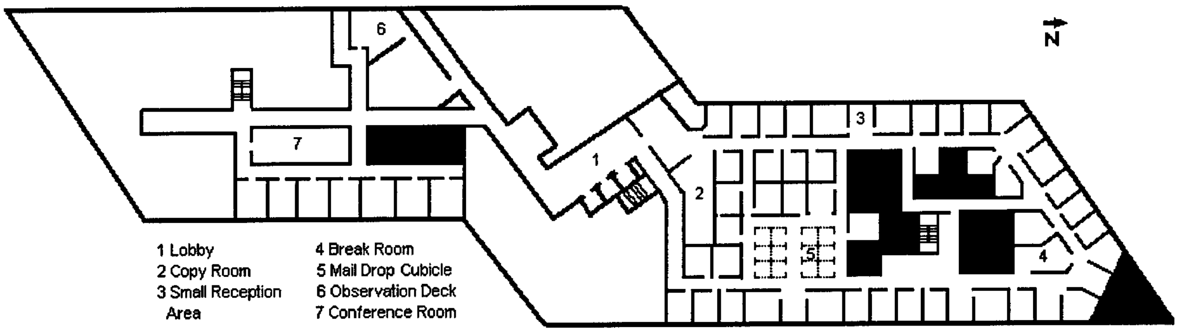

Figure 1. Layout of VE model of one floor of a large office building showing the location of destination rooms.

but has a limited FOV of 48 degrees horizontal x 36 degrees vertical. Localized, directional sound was provided in the enhanced environment through the HMD headphones. Custom software developed by the Institute for Simulation and Training (IST) controlled the presentation of trials and automatically recorded the data.

A raised circular platform with a safety rail allowed for simulated walking (see Figure 2). The platform, developed by IST has been used successfully in previous experiments (Singer, Ehrlich, & Allen, 1998; Lampton & Parsons, in preparation). A lightweight backpack worn by the participant provided connections to six position sensors, including the VE display and a hand controller. All of these movements were accurately tracked by an Ascension MotionStar. The position sensors allowed participants to walk in place and independently turn their head and body in any direction. The hand controller was used in aligning the participant's view and for controlling aerial viewing height for participants with access to an aerial view.

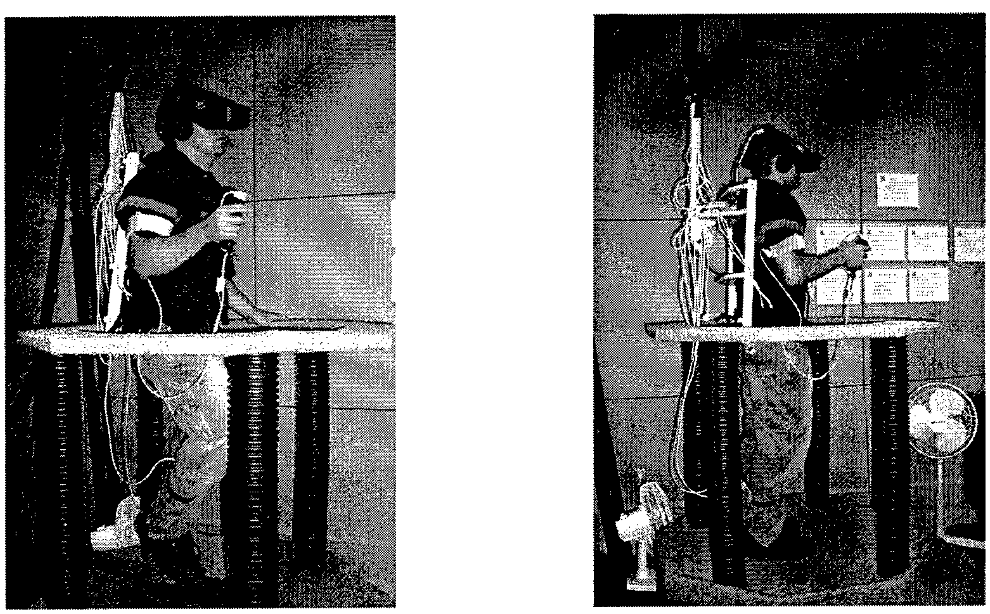

Figure 2. Walking platform and interface

Four questionnaires were used - two for measuring immersion, a third for measuring comfort (simulator sickness), and a fourth for collecting subject demographics. The Presence Questionnaire (PQ) and Immersive Tendencies Questionnaire (ITQ) were used for measuring immersion (Witmer & Singer, 1998) and the Simulator Sickness Questionnaire (SSQ) (Kennedy, Lane, Berbaum, & Lilenthal, 1993) was used to measure simulator sickness. A copy of the demographics questionnaire is included as Appendix A. A spatial abilities test, the Cubes Comparison Test, from the Educational Testing Service Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Dermen, 1990) was also administered. The Cube Comparisons Test requires mental rotation of a cube with letters, numbers, and shapes/figures on the cube faces to determine whether it is the same as a comparison cube.

Procedure. A researcher briefed participants about the purpose of the research, warned them of the potential for simulator sickness, and provided an overview of the research tasks. Participants were assigned randomly to the eight treatment groups shown in Table 1, with the restriction that equal numbers of men and women comprised each group. The experimental treatments map onto a factorial combination of two levels of viewing perspective, two levels of orientation cues, and two levels of environment type.

Table 1

Experimental Design

Environment Type	No Orientation Cues Added		Orientation Cues Added	
	Normal View Perspective	Aerial & Normal View Perspective	Normal View Perspective	Aerial & Normal View Perspective
Standard Environment	Control Group 0 (n=8)	Experimental Group 1 (n=8)	Experimental Group 2 (n=8)	Experimental Group 3 (n=8)
Enhanced Environment	Experimental Group 4 (n=8)	Experimental Group 5 (n=8)	Experimental Group 6 (n=8)	Experimental Group 7 (n=8)

Depending on group assignment, a participant experienced either the standard or enhanced VE, received orientation cues or did not, and could choose to view the VE from an aerial perspective or was restricted to viewing the VE from the normal perspective. Treatment Group 0, the control group, received the standard environment without orientation cues and viewed the VE from only the normal perspective. In contrast Treatment Group 7 received the enhanced environment with orientation cues and could view the environment from both the normal and aerial perspectives. The remaining treatment groups listed in Table 1 fell somewhere in between these extremes.

After being briefed on the procedure and completing the Cube Comparisons Test, SSQ, ITQ, and demographic surveys, participants practiced procedures in the VE to introduce them to the equipment and to familiarize them with VE movement techniques. Sensors attached to their arms and legs captured arm position and walking movements that were mirrored in the movements of the participant's avatar. Other sensors on the

HMD and backpack recorded body and head orientation. Participants in the aerial groups used the hand controller to change their viewing perspective. Participants remained in the practice VE for a maximum of ten minutes followed by a five-minute break.

Participants then received instructions specific to their treatment group. Aerial groups could view the VE from heights of 15, 30, and 120 meters for a period of up to one minute. After one minute, they automatically returned to the normal perspective view. They could choose aerial views one time or many times, but the viewing period was limited to one minute each time. Viewing in which participants can switch between egocentric and exocentric views has been termed bicentric viewing (Salzman, Dede, Loftin, & Ash, 1999). Viewing heights were selected so that participants could see either the whole third floor layout at once at 120 meters or parts of the layout at 15 and 30 meters. At a viewing height of 15 meters, about one-eighth of the environment was visible in a single glance, but objects within the environment could be recognized easily. At 30 meters, one-fourth of the environment was simultaneously visible, but objects were more difficult to recognize. Figure 3 shows a view of the enhanced VE from a height of 30 meters. When aerial group participants initially pressed the trigger button on their hand controller, they gradually ascended to 15 meters. They could increase viewing height by pressing the trigger button a second or third time. While in the air, participants could further explore the environment by flying to other locations (accomplished by walking in place). To return to ground level they pressed the thumb button on their hand controller, and gradually descended to reenter their virtual body at the exact location where they left it when they started to fly. While flying, their view was pitched 30 degrees downward from the horizontal plane when facing straight ahead to minimize neck strain. Of course, participants could alter the pitch angle by moving their head.

Groups exposed to the themed environment encountered sights and sounds associated with each of four themed quadrants. Each destination had a memorable theme object located inside the room and an associated sound that became louder as the participant approached the destination room. Figure 4 shows the normal perspective view of one destination room enhanced with a sports theme object. Additional theme objects were positioned along the building corridors, but no sounds were associated with these objects. The themes embedded in the quadrants were a tropical island theme, a wild animals theme, an extraterrestrial (or outerspace) theme, and a sports theme. Upon encountering a theme object inside a destination room, participants were asked to identify the theme represented by that object. Hypothetically, this would allow the participants to categorize the building into four distinctive sectors.

The orientation cue groups were asked to relate their current position to their starting position (in the lobby) marked by a virtual flagpole. This was accomplished by having participants turn and face the flagpole upon reaching each destination. The flagpole, visible throughout the environment, served as a global orientation cue that allowed participants to update their position continuously based on their known starting position. An additional orientation cue was an arrow projecting from the chest of the participant's avatar. The arrow indicated their current heading and provided a means to align their virtual body so as to avoid collisions with walls and doorways.

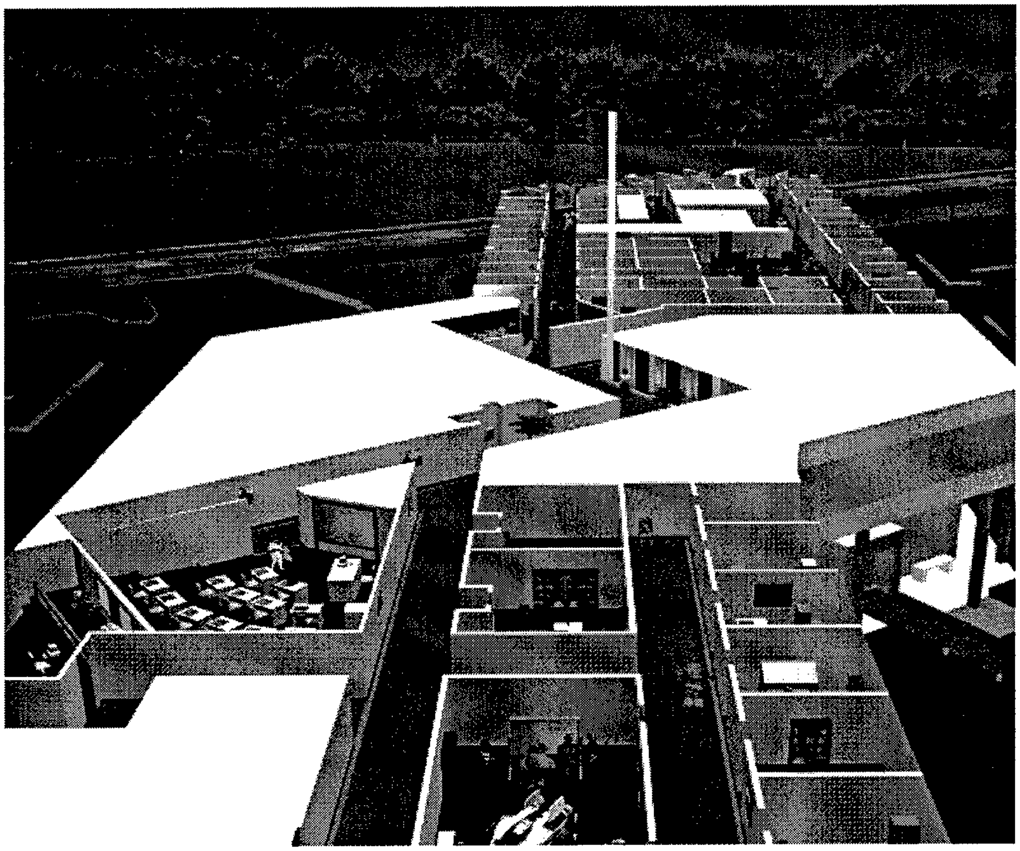

Figure 3. Enhanced VE at 30-meter viewing height.

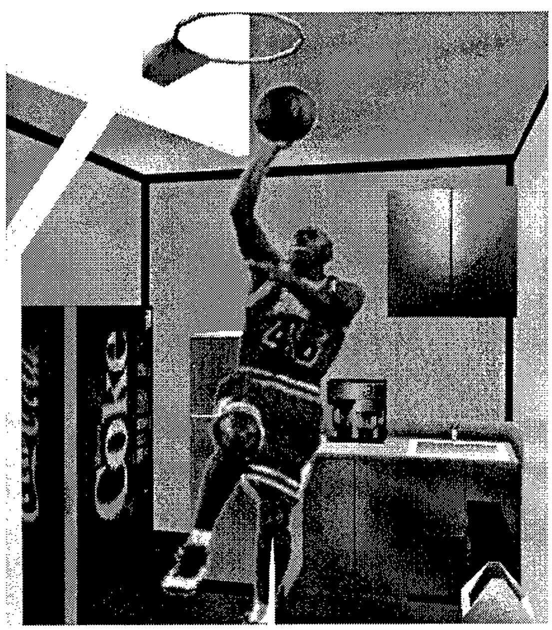

Figure 4. Normal perspective view of a destination room enhanced with a sports theme object.

The training was conducted in three distinct phases. During the first training phase, all participants took a guided tour of the VE, pausing at each destination room, and identifying it by name. Participants actively followed a virtual tour guide to each destination. The virtual tour guide verbally described the 'non-theme related' distinguishing features of each destination along the way. Figure 5 shows a picture a female tour guide avatar and the avatar representing the male participant. The gender of the tour guide was always opposite the participant's gender. In the second training phase, participants explored the VE freely, while trying to accomplish the assigned goal of locating and identifying each previously visited destination. In the final training phase, participants attempted to take the shortest route from the third floor lobby to each named destination. If the participants did not find the destination within three minutes, they were verbally guided to it.

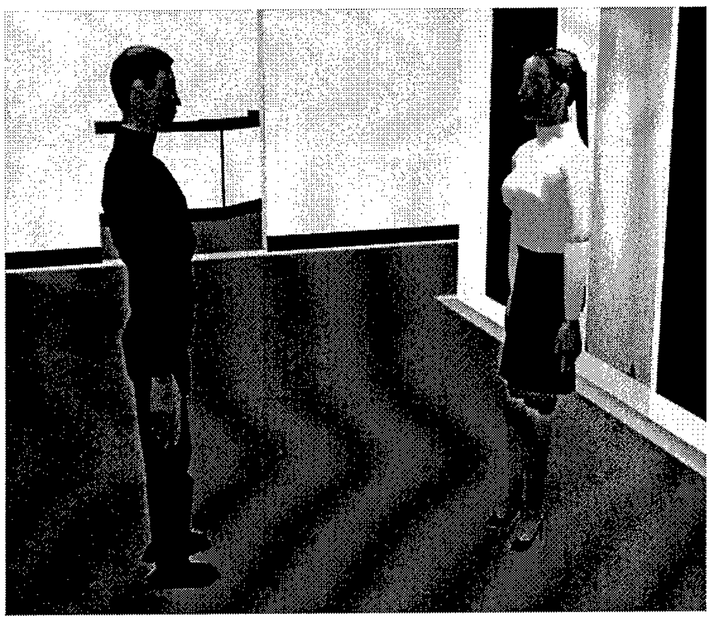

Figure 5. Female avatar tour guide and male avatar representing the participant.

Measuring the configuration knowledge acquired during the training phases was accomplished by administering three separate tests:

(1) The Projective Convergence Test required participants to indicate the direction and distance to destination rooms from three different sighting locations. Participants in the VE indicated a destination's direction by turning to face the destination and the distance to the destination by walking the perceived distance to the target without vision. Previous research (Witmer and Sadowski, 1998) found that distance estimates produced by this method are more accurate than verbal distance estimates in both the real world and VE. Measures selected for this test include heading error to assess the accuracy of estimating bearing and distance error for assessing the accuracy of estimating distance.

(2) The Most Direct Route Test required participants in the VE to determine the shortest route between two named locations. Participants completed this task for six

destination pairs. Measures included the mean distance error in locating the destinations based on the shortest possible distance and the mean time to locate the destinations.

(3) The Room Placement Test required participants to place labeled "cutouts" of the destination rooms in their "correct location" on a map outline of the third floor. This computer-based test required participants to click and drag the rooms to their "correct" position on the map. Measures selected for this test include distance error (the distance between correct location and the placed location) and room placement time (the time required to place all six rooms on the map outline).

Analyses. A 2x2x2 (perspective view by orientation cue by environment type) factorial MANCOVA design was used to analyze the training phase data. The covariate was the score on the Cube Comparisons Test, computed by subtracting the number of incorrect items from the number of correct items. Separate ANOVA's were then performed for the covariate and for each dependent measure. The dependent measures included number of rooms found during free exploration and total search time, total distance traveled, and number of rooms found during the destination search training.

A 2x2x2 (perspective view by orientation cue by environment type) factorial MANCOVA design was used to analyze the configuration knowledge test results. The covariate was the score on the Cube Comparisons Test. Separate ANOVA's were then performed for the covariate and for each dependent measure. The dependent measures for the Projective Convergence Test were angular heading error and distance error, while the dependent measures for the room placement test were distance error and placement time. The dependent measures for the Most Direct Route Test were mean distance error and travel time. The distributions for all of the dependent measures except heading error were markedly nonnormal (positively skewed) and were transformed using the appropriate power transformations (See Appendix B). The transformed data approximated a normal distribution. Correlation coefficients between performance during the last two training phases and test performance were computed to identify the training measures that best predict test performance. Correlation coefficients were also calculated between SSQ, PQ, ITQ, and test performance. To further explore predictors of configuration knowledge, standard and hierarchical regression analyses were performed. All analyses, including correlational analyses, used the transformed values for the dependent measures. It is important to note that all of the dependent measures except distance error on the Most Direct Route Test and heading error on the Projective Convergence Test were transformed using inverse power functions. Inverse transformations reverse the direction of correlation coefficients, so that they may appear to be in the wrong direction.

Results and Discussion

Performance during Configuration Training Phases. During the exploration and destination search training phases, the number of rooms correctly located was recorded. The total search time and distance traveled during the search training phase were also recorded. Table C-1 in Appendix C presents the means and standard deviations for these training performance measures. These measures were used in a 2x2x2 MANCOVA to determine the effects of viewing perspective, environment type, and orientation cues on

training performance. The covariate was the score on the Cube Comparisons Test. There was a significant main effect for viewing perspective, F (4,51) = 5.69, $p < .001$, and for environment type, F (4,51) = 2.80, $p < .05$. Orientation cues did not exert a significant effect, F (4,51) = 2.05, $p = .10$, and there were no significant interactions. The effect of the covariate, cube comparisons score, was not significant, F (4,51) = 2.5, $p = .054$.

Follow-up ANOVAs revealed that aerial views increased the average number of rooms found during the search training phase, $F(1,54) = 18.78$, $p < .001$, but not during the exploration phase, $F(1,54) = .62$, $p = .43$. Aerial views also decreased the total search time, $F(1,54) = 5.16$, $p < .05$, and distance traveled, $F(1,54) = 14.25$, $p < .001$. Additional ANOVAs showed that in the enhanced environment more rooms were found during both search training, $F(1,54) = 8.68$, $p < .01$, and free exploration, $F(1,54) = 6.63$, $p < .05$, than in the standard environment. The sounds associated with themed objects at each destination likely helped participants find more rooms in the enhanced environment. The saliency of the themed objects may have also aided in recalling the location of the destination rooms. Total search time and distance traveled did not vary significantly with environment type. None of the ANOVA interactions were significant.

The individual participants determined how much time they spent in the aerial view during free exploration and during search training. Overall, participants used the aerial view more during free exploration than during the destination search phase (see Table 2). The participants also selected their viewing height. Table 2 shows the mean time spent at each viewing height in each training phase. Note that most participants spent most of their aerial time at the 15-meter and 30-meter heights, and that little time was spent at the highest altitude. Participants chose the 15 and 30-meter viewing heights equally as often during destination search, but selected the 30-meter height more often during free exploration. This suggests that the 30-meter viewing height was preferred for exploring the environment as a whole, but 15 and 30-meter heights were chosen equally when locating specific destinations.

Table 2

Mean Time Spent at each Viewing Altitude by Training Phase

Training Phase	Viewing Time (in secs) Spent at each Altitude				
	15m	30m	120m	All Altitudes	Ground Level
Free Exploration	34.51	47.55	3.12	85.18	497.70
Destination Search	31.17	30.86	0.91	62.94	354.89

<u>Performance on Configuration Knowledge Tests.</u> The effects of experimental treatments designed to enhance configuration knowledge were assessed using MANCOVA. There was a significant main effect for viewing perspective, $F(6,50) = 3.44$, $p < .01$, but no effects for either orientation cues or environment type. There were no significant interactions. The effect of the covariate, cube comparison score, was also significant, $F(6,50) = 2.71$, $p < .05$.

Of the six dependent measures, viewing perspective had significant effects on projective convergence angular error, $F(1,55) = 8.99$, $p < .01$, and distance error, $F(1,55) = 10.01$, $p < .01$, as well as for the room placement distance error, $F(1,55) = 8.27$, $p < .01$. No effects were found for room placement time, or for either Most Direct Route Test measure. The covariate was significantly related to projective convergence angular error, $F(1,55) = 5.54$, $p < .05$, and distance error, $F(1,55) = 6.22$, $p < .05$, and also direct route test distance error, $F(1,55) =10.72$, $p < .01$, and search time, $F(1,55) = 14.07$, $p < .001$. The covariate affected neither Room Placement Test measure. Untransformed means and standard deviations for each dependent measure by viewing perspective, orientation cues, and environment type are shown in Table C-2 in Appendix C.

For the aerial group Pearson correlations were computed to examine relationships between the amount of time spent in the aerial view and subsequent performance on the configuration knowledge tests. Significant correlations were obtained between free exploration aerial time and both room placement distance, $r(31) = .36$, $p < .05$, and heading error, $r(31) = -.48$, $p < .01$. The direction of these correlations and correlations between aerial time and other configuration knowledge measures indicated that increased aerial time during free exploration was associated with increased configuration knowledge. It appears that during free exploration, participants were using the aerial view to locate destinations relative to one another and to investigate the layout as a whole. Significant correlations of aerial time with search distance error, $r(32) = .56$, $p < .001$, search time, $r(32) = -.57$, $p < .001$, and heading error, $r(32) = .44$, $p < .05$, for the search training phase indicates that increased aerial time during search was associated with poor performance. During the search task, participants may have used the aerial view as a crutch to locate a particular destination, rather than as a tool to enhance their knowledge of the building configuration. This suggests that the advantage of an aerial view in acquiring configuration knowledge depends on how the participants use the aerial view.

For the orientation cue group, a one-tailed t-test was performed to determine whether the local orientation cue resulted in fewer collisions. The collision rate was .45 collisions per minute for those participants who had orientation cues and .78 collisions per minute for those who did not. However a one-tailed t-test revealed that this difference was not statistically reliable, $t(61) = 1.31$, $p = .10$.

Room Placement Reversals and Top Performers. A small number of participants reversed the placement of rooms so that rooms located at the North End of the building were placed at the South End and vice versa. This happened despite attempts to reorient participants before testing their room placement . Five participants completely reversed their room placement and three others made partial reversals. These participants tended to be some of the poorest performers. Of those who reversed, three were in the control group. Seven of the eight who reversed had only a ground-level view, while only one had an aerial view. Five of the eight reversals occurred in the standard environment. Reversals indicate disorientation, which can have serious practical consequences for tasks dependent on accurate spatial knowledge. Five of those who reversed reported that they had a good sense of direction, while three reported they did not. Table 3 shows the number of participants in each navigation condition who reversed their room placement.

Table 3

Number of Participants Who Reversed Room Placement by Navigation Aid Category

	No Orientation Cues Added		Orientation Cues Added		
	Normal Viewing	Aerial Viewing	Normal Viewing	Aerial Viewing	Totals
Standard Environment	3 *	0	2	0	5
Enhanced Environment	2	0	0	1	3
Totals	5	0	2	1	8

* Control group had no navigation aids.

Table 4 shows the number of performers by navigation aid and condition who were among the top 25% of performers on the room placement test (upper quartile) in our sample. Twelve of the sixteen top performers were in the aerial group. Only six of the sixteen were in the enhanced environment, while ten were in the standard environment. Eleven of the sixteen top performers had orientation cues while five did not. Thirteen of the top performers claimed to have a good sense of direction while three did not.

Table 4

Number of Top Performers on Room Placement Test by Navigation Aid Category

	No Orientation Cues Added		Orientation Cues Added		
	Normal Viewing	Aerial Viewing	Normal Viewing	Aerial Viewing	Totals
Standard Environment	1*	4	0	5	10
Enhanced Environment	1	0	2	3	6
Totals	2	4	2	8	16

* Control group had no navigation aids.

<u>Relatedness of Measures of Configuration Knowledge.</u> Administering three different tests of configuration knowledge was an attempt to ensure that the various aspects of configuration knowledge were adequately measured. If all tests measure the same thing, then the test scores should be significantly correlated. To the extent that these tests measure different aspects of configuration knowledge, the magnitude of the relationships should be less. Table 5 reveals many significant correlations. All of these significant correlations were in the predicted direction. Except for the Room Placement Test, measures derived from the same test were significantly intercorrelated. The

distance error and the angular error from the Projective Convergence Test were significantly correlated, $\underline{r}(64) = .40$, $\underline{p} < .001$, as were the Most Direct Route Test search time and distance error, $\underline{r}(64) = -.89$, $\underline{p} < .001$. Room placement times and room placement distance errors were not significantly correlated. The time to place the rooms may have been determined more by how careful the participants were in attempting to place the rooms precisely or by their proficiency in using the mouse interface rather than by how well they had learned the layout.

Table 5

Intercorrelations Among Transformed Measures of Configuration Knowledge

	Most Direct Route Test		Room Placement Test		Projective Convergence Test	
	Distance Error	Search Time	Distance Error	Placement Time	Heading Error	Distance Error
Route Distance Error	1.0	-.89***	-.44***	-.14	.66***	-.43***
Route Search Time	-.89***	1.0	.46***	.17	-.56***	.45***
Placement Distance	-.44***	.46***	1.0	.18	-.44***	.49***
Placement Time	-.14	.17	.18	1.0	-.28*	.22*
Heading Error	.66***	-.56***	-.44***	-.28*	1.0	- .40***
Projective Distance Error	-.43***	.45***	.49***	.22*	-.40***	1.0

Based on a one-tailed test of significance, * p < .05, ** p < .01, *** p < .001

Some measures across tests were also significantly correlated (See Table 5). Angular error on the Projective Convergence Test was significantly correlated with search time and distance error on the Most Direct Route Test, as well as with placement distance on the Room Placement Test. Distance error on the Projective Convergence Test was significantly correlated with both search time and distance error on the Most Direct Route Test and with placement distance error and placement time on the Room Placement Test. Search time on the Most Direct Route Test was significantly correlated with placement distance error, but not with placement time on the Room Placement Test. Distance error on the Most Direct Route Test was not significantly correlated with either room placement distance or with placement time. The pattern of significant correlations suggests that our tests are all measuring the same or closely related knowledge. We maintain that the common knowledge being measured is configuration knowledge. Room placement time was the weakest measure of configuration knowledge, correlating significantly only with Projective Convergence Test heading error and distance error.

Most Direct Route Test measures should correlate more highly with the projective convergence measures than with Room Placement Test measures because no change in perspective is necessary between the route test and the projective convergence tasks. In

contrast, a perspective change is required to go from the route test to the room placement task. As expected, the route test measures were significantly correlated with both projective convergence measures; in contrast, they were significantly correlated with only one of the room placement test measures. The highest correlation found among these measures is between Most Direct Route Test distance error and heading error.

A perspective change is also necessary to go from the projective convergence tasks to the room placement task. Yet, placement distance error on the Room Placement Test was moderately and significantly correlated with both Projective Convergence Test measures. Waller (1999), who used map placement and projective convergence tests, obtained comparable results. He explains these results by suggesting that the processes responsible for accurate egocentric representation of an environment are not wholly distinct from the processes that enable an exocentric representation. He further speculates that egocentric and exocentric representations depend on the same knowledge base and probably develop together. Waller (1999) maintains that people in his experiment performing the projective convergence task probably did not generate a bird's-eye-view perspective. Yet, the map placement task by its very nature requires the generation of a bird's-eye-view perspective. In our research, half of the participants were provided a bird's-eye-view of the VE. Some of the other participants who placed the rooms accurately on the Room Placement Test certainly generated the bird's- eye-view when asked to do so, as demonstrated by their room placement accuracy. We maintain that having the knowledge necessary to generate a bird's-eye-view represents a more complete state of configuration knowledge than is represented by being able to point to unseen targets. Supporting our view, Waller (1999) found that measures that rely on the ability to change perspective from a ground-level view to an aerial view were more predictive of learning about spaces than were pointing measures.

Participants afforded an aerial view have a higher correlation between room placement distance error and both route distance error, $\underline{r}(32) = -.69$, $\underline{p} < .001$, and search time, $\underline{r}(32) = .71$, $\underline{p} < .001$, than subjects who had no aerial view and had to generate an aerial view. The correlations of room placement distance with route test distance error and search time were $\underline{r}(32) = -.07$, $\underline{p} = .36$, and $\underline{r}(32) = .19$, $\underline{p} = .15$, respectively, for those without an aerial view. Essentially, there was no reliable relationship between the room placement distance measure and route test measures for those who did not have an aerial view. The aerial group also exhibited higher correlations between route test measures and projective convergence measures and between room placement and projective convergence measures than did the group with no aerial view. The higher correlations among the dependent measures for the aerial group coincided with better overall performance for that group. This suggests that correlations among different measures of configuration knowledge may increase as the participants increase their knowledge of the configuration. It further suggests that providing an aerial perspective improves spatial knowledge overall.

<u>Predictors of Configuration Knowledge</u>. A number of variables were investigated as possible predictors of configuration knowledge. These include Gender, PQ Scores, ITQ scores, SSQ scores, Cube Comparison Test Scores, reported Sense of Direction, and

Search Time, Number of Destinations Found, and Collision Rate during the training phases of the experiment. Table 6 presents the results of a one-tailed test of Pearson correlations between potential predictors of spatial knowledge and transformed measures of configuration knowledge. The results show that many of the predictors were

Table 6

Correlates of Configuration Knowledge using Transformed Measures

Predictor	Most Direct Route Test		Room Placement Test		Projective Convergence Test	
	Distance Error	Search Time	Distance Error	Placement Time	Heading Error	Distance Error
1. Cube Total	-.43***	.48***	.17	.16	-.26*	.29*
2. Sense of Direction	-.07	.05	.10	.22*	-.25*	.24
3. Gender	-.28*	.32**	.30**	.16	-.25*	-.22*
4. ITQ Total	-.13	.10	.19	-.04	-.21*	.07
5.Computer Confidence	-.25*	.32**	.26*	.22*	-.12	.28*
6. Exploration # Collisions	.29**	-.25*	-.19	.07	.28*	-.17
7. Search Collision Rate	.16	-.11	-.26*	.17	.24*	-.32**
8. Search Speed	-.44***	.55***	.28*	.15	-.33**	.18
9. Destinations Found - Explore	-.25*	.33**	.27*	.28*	-.19	.33**
10. Destinations Found - Search	-.39***	.32**	.38***	.18	-.41***	.49***
11. Destinations ID'd - Search	-.32**	-.36**	.24*	.41***	-.25*	.47***
12. Viewing Perspective	-.12	.04	.32**	.12	-.32**	.35**
13. Orientation Cues	-.10	.08	.16	-.22*	-.11	.02
14. Environment Type	.11	-.17	-.10	-.03	-.01	.04
15. SSQ Total	.20	-.27*	-.02	.04	.09	.03
16. PQ Total	-.32**	.33**	.05	-.12	-.17	.06

Based on a one-tailed test of significance, * $p < .05$, ** $p < .01$, *** $p < .001$

significantly correlated with the configuration knowledge measures. Except for a positive correlation between orientation cues and room placement time measure, all of the significant correlations shown in Table 6 were in the predicted direction.
The best predictors of the configuration knowledge measures were the total score on the Cube Comparisons Test, gender, confidence in using computers, destination search speed, and the number of destinations found and identified during training. Overall, participants who scored high on the Cube Comparisons Test, reported high confidence in using computers, moved faster during training, or found and identified relatively more destinations during training performed better on configuration knowledge tests. The number of destinations correctly identified during the search task was among the best predictors, significantly predicting all six of the configuration knowledge test measures.

Collision measures were relatively good predictors of configuration knowledge. The number of collisions during the free exploration was a significant predictor of three of six configuration knowledge measures. Collision rate during destination search training, the number of collisions divided by travel time, yielded a similar pattern of results. The average collision rate was 0.61 collisions per minute. In general, participants who had fewer collisions had better scores on configuration knowledge tests. These results corroborate previous research where repeated collisions (average of 4.98 collisions per minute) appeared to disorient participants, and were associated with poorer route learning (Witmer, et al., 1995). The number of collisions in a VE may be indicative of an individual's proficiency with the interface that controls movement in the VE. The speed of moving through the VE may also be indicative of interface proficiency. Movement speed during the destination search training phase correlated significantly with four of six configuration knowledge measures. Waller (1999) has shown that interface proficiency impacts spatial learning in a VE. Our results are consistent with Waller's in that individuals who are less proficient using the walking interface have degraded performance on tests of configuration learning.

Those individuals who experienced more presence as measured by the PQ and less simulator sickness as measured by the SSQ performed better on the Most Direct Route Test measures than those who reported less presence. The ITQ scores significantly predicted projective convergence heading error, but little else. Finally, participants who had more confidence in their ability to use computers performed significantly better than their less confident counterparts on the Most Direct Route Test measures, Room Placement Test measures, and Projective Convergence Test distance error.

Gender was significantly correlated with Room Placement Test distance error, Projective Convergence Test heading error and distance error, and both Most Direct Route Test measures, with males performing better than females. However, if a partial correlation between gender and these measures is computed with spatial ability as measured by Cube Comparisons Test partialed out, gender is significantly correlated only with Room Placement Test distance error, $r(64) = .26$, $p < .05$. Thus, individual differences in spatial ability appear to account for most of the variance attributed to gender. This suggests that spatial ability, rather than gender per se, is responsible for most of the apparent gender differences in configuration learning.

Predictors 1 through 14 in Table 6 were entered into a regression to determine what proportion of the variance of scores on the tests of configuration knowledge was accounted for by these predictors. The dependent measures except for the heading errors were transformed before performing the regressions to normalize the data. The heading errors did not require a transformation. The proportion of variance accounted for by the combined effects of these predictors is shown as the total in the first row of Table 7. The regression model accounted for 49% of the variance in direct route test distance error, $F(14, 47) = 3.21$, $p < .001$, 61% of the variance in the direct route test search time, $F(14, 47) = 5.31$, $p < .001$, 41% of the variance in room placement distance error, $F(14, 47) = 2.31$, $p < .05$, 29% of the variance in the room placement time, $F(14, 47) = 1.38$, $p = .2$, 47% of the variance in the heading error, $F(14, 47) = 2.91$, $p < .01$, and 48% of the variance in projective convergence distance error, $F(14, 47) = 3.09$, $p < .01$.

Conceptually, the first fourteen predictors in Table 6 can be grouped into four categories: (1) personal traits, (2) navigation aids (3) interface proficiency; and (4) wayfinding during training . Personal traits include the Cube Comparison Test score, self reported sense of direction and confidence in using computers, ITQ score, and gender. All personal traits, except gender, either measure specific abilities or reported competencies in specific areas. Navigation aids include variables that were specifically manipulated in this research to enhance configuration learning. These variables include viewing perspective, orientation cues, and environment type. Interface proficiency includes the number of collisions during free exploration, the collision rate during destination search training, and the movement speed through the VE. Wayfinding during training variables include the number of rooms located during both training phases and the number of destinations correctly identified during the destination search training. Separate regression models were tested for each of the four sets of variables and for each of the dependent measures. The proportion of the variance accounted for by variable set by dependent measure is shown in Table 7. The table also indicates which of the regression models were significant.

In analyzing the variable sets separately, "wayfinding during training" variables predicted configuration knowledge measures most consistently, but interface proficiency significantly predicted five of the six measures, and personal traits significantly predicted four of the six measures. Navigation aid variables significantly predicted only two of the six measures. Table 7 data reflect the results when predictor variable sets are considered separately; hence, the variance accounted for in Table 7 by a variable set might be the same variance accounted for by other variable sets. To identify the unique variance contributed by each variable set, a hierarchical regression analysis was performed.

The variable sets were entered sequentially using a hierarchical regression procedure. The order was determined by entering variable sets such that sets entered later were deemed unlikely to be causal for earlier entered sets. This procedure enabled identification of the variable sets that contributed most to the prediction of configuration knowledge. Table 8 shows the results of the hierarchical regression analyses. The data in the first four rows of the table consist of squared multiple semipartial correlation

Table 7

Proportion of Variance (R^2) Accounted for by Predictors of Configuration Knowledge Measures

Predictor Variable Sets	Most Direct Route Test		Room Placement Test		Projective Convergence Test	
	Distance Error	Search Time	Distance Error	Placement Time	Heading Error	Distance Error
Total (All 14 predictors)	.49***	.61***	.41*	.29	.47**	.48**
Personal Traits	.23**	.29***	.13	.10	.18*	.18*
Navigation Aids	.04	.04	.14*	.07	.11	.13*
Interface Proficiency	.28***	.36***	.19**	.05	.19**	.13*
Wayfinding during Training	.16*	.17*	.15*	.19**	.18**	.29**

* Regression significant at $p < .05$. ** Regression significant at $p < .01$.
*** Regression significant at $p < .001$.

Table 8

Increment in Proportion of Variance (R^2) Accounted for by Sequentially Entering Predictor Variable Sets in a Hierarchical Regression Analysis

Predictor Variable Sets	Most Direct Route Test		Room Placement Test		Projective Convergence Test	
	Distance Error	Search Time	Distance Error	Placement Time	Heading Error	Distance Error
Personal Traits	.227*	.292***	.134	.102	.221*	.187*
Navigation Aids	.041	.021	.130*	.042	.137*	.123*
Interface Proficiency	.169**	.239***	.108*	.027	.070	.062
Wayfinding during Training Phases	.051	.061	.037	.119	.036	.107*
Total (All predictors)	.489***	.612***	.407*	.291	.465**	.479**

* $p < .05$. ** $p < .01$. *** $p < .001$.

coefficients. Data in the last row represents the total proportion of the variance accounted for by all of the variable sets combined and is the sum of the squared multiple semipartial correlation coefficients (may not be exact due to rounding error). The squared multiple semipartial correlation coefficient represents the change in R^2 as each set is added, or the unique contribution of each predictor set in predicting the dependent measures. Asterisks denote that the F-test for the change in R^2 is statistically significant.

As shown in Table 8, personal traits and navigation aids contributed the most unique variance to the Projective Convergence Test measures, but wayfinding during training also made a significant unique contribution. Navigation aids and interface proficiency reliably predicted Room Placement Test distance error; however, none of the variables reliably predicted room placement time. Personal traits and interface proficiency best predicted the Most Direct Route Test measures.

Presence. A 2x2x2 factorial ANOVA was performed to determine if type of environment, orientation cues, or the addition of an aerial view influenced the amount of presence reported. The participants reported feeling a sense of presence in both the standard and enhanced environments, with or without orientation cues, and with or without an aerial view. None of these variables significantly affected the sense of presence as measured by the PQ. The mean PQ total score was $M = 97.35$, $SD = 11.93$.

A significant negative correlation between presence and simulator sickness was obtained, $r(64) = -.57$, $p < .001$. A negative relationship between presence and simulator sickness has been commonly found across numerous experiments (Knerr et al., 1998). The strength of the association in this experiment is indicative of high levels of simulator sickness, where the severity of symptoms are high enough to strongly impact reported presence in the VE.

As mentioned earlier and shown in Table 6, presence was significantly correlated with only two of the six performance measures. Participants who reported more presence performed better on the Most Direct Route Test measures than those who reported less presence. It is not clear why these measures were related to presence and other measures of configuration knowledge were not. One possible reason this may have occurred is that the Most Direct Route Test was performed in the VE with unrestricted access to the VE. The Projective Convergence Test, on the other hand, required that participants' vision be obscured after the destination direction was estimated. The Room Placement Test was not conducted in the VE, and therefore might not be expected to be related to presence in the VE.

Presence was also correlated significantly with scores on the Cube Comparisons Test, $r(64) = .26$, $p < .05$. In other words, participants with more spatial ability experienced more presence in performing a spatial task in the virtual environment than those with less spatial ability. Contrary to expectation, the ITQ was not a significant predictor of presence, $r(64) = .16$, $p = .11$. The direction of the correlation was in the predicted direction, however. Based on our data, it appears that reported levels of presence while performing a spatial task may be more influenced by the environment and task variables than by individual differences.

Simulator Sickness. A 2x2x2 factorial ANOVA was performed to determine if type of environment, orientation cues, or the addition of an aerial view influenced simulator sickness scores of the participants who completed the experiment. Participants reported moderate levels of simulator sickness in both the standard and enhanced environments, with or without orientation cues, and with or without an aerial view. None

of these variables significantly affected the severity of simulator sickness symptoms as measured by the SSQ. The mean SSQ total score was $\underline{M} = 32.55$, $\underline{SD} = 31.93$. There was a significant correlation between total SSQ scores and gender, $\underline{r}(64) = .26$, $\underline{p} < .05$, with females reporting more severe symptoms than males. Simulator sickness in this research was not significantly related to having previously experienced motion sickness, $\underline{r}(64) = -.02$, $\underline{p} = .44$, nor was it significantly related to self-rated motion sickness susceptibility, $\underline{r}(64) = .17$, $\underline{p} = .08$. Of the six configuration knowledge measures, simulator sickness scores were correlated significantly only with Most Direct Search Test search time, $\underline{r}(64) = -.26$, $\underline{p} < .05$. SSQ scores are frequently correlated with time measures because as participants spend longer time periods in the VE their simulator sickness symptoms increase. None of the measures of accuracy (e.g., heading error, room placement distance) was significantly related to SSQ scores.

Sixteen of eighty participants in this research could not complete the experiment because of severe simulator sickness symptoms. The mean VE exposure time (in minutes) before withdrawing from the experiment was $\underline{M} = 27.54$, $\underline{SD} = 2.6$. The VE exposure was not continuous, as participants took short breaks between training phases and when needed to alleviate physical discomfort. Eleven of those withdrawing from the experiment were females and five were males. Thirteen of those withdrawing were exposed to the standard environment while only three dropouts were exposed to the enhanced environment. Seven of the dropouts had orientation cues and nine did not. The mean SSQ total score was $\underline{M} = 60.54$, $\underline{SD} = 32.98$ for those who withdrew. This mean SSQ score is nearly twice that of those who completed the experiment. Those who withdrew reported no more motion sickness in their past, $\underline{t}(78) = .78$, $\underline{p} = .44$, or any greater susceptibility to motion sickness, $\underline{t}(78) = 1.84$, $\underline{p} = .07$, than those who completed the experiment. However both subjects who reported the maximum susceptibility to motion sickness dropped out of the experiment.

Experiment 2: Expert vs. Novice Performance

Method

Participants. After the 64 participants in the first experiment, henceforth referred to as the "novice" group, completed the experiment, another group of eight participants was formed to comprise the "expert" group. This expert group consisted of the six researchers who collected the data for the novice group and the two primary developers of the VE. The experts ranged in age from 19 years to 54 years; the mean age was 31.38 years. All participants had normal vision uncorrected or corrected with contact lenses or glasses. All members of the expert group, except one, had been immersed in the VE during development and/or pilot testing. Additionally, the expert group had extensive non-immersive exposure to both environments (enhanced vs. non-enhanced) and both viewing perspectives (aerial vs. grounded) by observing at least 10 novice group participants during training and testing phases. While the exact exposure time to each environmental version and viewing perspective varied among the expert group participants, each had attained sufficient route knowledge to easily navigate to any

destination from another location in the VE and were presumed to have acquired accurate mental maps of the VE.

Equipment and Materials. Basically, the same equipment and materials used in the first experiment were used in this experiment. However, the expert group did not complete any of the questionnaires.

Procedure. The extensive exposure the expert group had to the VE would allow them to traverse each route segment with negligible distance error and minimal traversal times. For that reason, the Most Direct Route Test was not administered for the expert group. Of more interest to the authors was the performance of the expert group on the Projective Convergence and the Room Placement tests. The proficiency of the experts on these two tests provided an indication of what one may expect regarding peak performance on each measure and produced data to compare the performance of the novice and expert groups.

The participants in the expert group were immersed in the practice VE for at least 5 minutes to allow them to adapt to the equipment and reacquaint themselves with the walking procedure. Walking in the practice environment also allowed the experts to calibrate their walking movements with movement through the VE. After a 5-minute break, the participants were asked to perform the Projective Convergence Test. Upon completing the Projective Convergence Test, the experts used a desktop computer to complete the Room Placement Test. On the test day, expert group participants were not exposed to the VE, immersively or non-immersively, prior to testing. This contrasts with the novice aerial and grounded groups who were immersively exposed to the VE on the same day that they were tested.

Results and Discussion.

As in previous analyses, the data deviated from a normal distribution and required transformation. The average distance error from the Projective Convergence Test and the average distance error and room placement times for the Room Placement Test were normalized through a power transformation. It was not necessary to transform the average heading error from the Projective Convergence Test. The results reported below reflect analyses using the three transformed variables and the single non-transformed variable.

An initial MANOVA, using the two dependent measures of the Projective Convergence Test and the two dependent measures for the Room Placement Test, indicated a significant difference between the novice and expert groups $F(4,67) = 6.93$, $p < .001$. There was a significant difference between the expert and novice groups for both measures of the Projective Convergence Test. The average distance errors were significantly different, $F(1,70) = 6.62$, $p < .05$, as were the average heading errors $F(1,70) = 11.82$, $p < .01$. The average distance errors on the Room Placement Test were also significantly different $F(1,70) = 16.80$, $p < .001$; however, the room placement times were not significantly different.

Another MANOVA, using the two dependent measures for the Projective Convergence Test and two dependent measures for the Room Placement Test, assessed significance for three levels of VE exposure (i.e., grounded, aerial, and expert exposure). The MANOVA indicated a significant main effect for exposure condition, $F(8, 132) = 4.94$, $p < .001$. ANOVAS revealed significant differences for the Projective Convergence Test average distance errors $F(2,69) = 7.58$, $p < .01$ and average heading errors $F(2,69) = 10.02$, $p < .001$. The average distance errors on the Room Placement Test were also significantly different $F(2,69) = 12.75$, $p < .001$, while the room placement time was, yet again, not significantly different among the groups.

Post Hoc comparisons (using a Scheffe adjustment for type I error rate inflation) revealed significant differences between the three groups on the four dependent measures. Analyses indicated that there were significant differences between the expert group and the grounded group for both dependent measures of the Projective Convergence Test - average distance error, $p < .01$ and average heading error, $p < .001$. On the Room Placement Test the average distance error was significantly different between the expert and grounded exposure groups, $p < .001$. There were also significant differences between the expert group and the aerial exposure groups for the Projective Convergence Test average heading error, $p < .05$, and for the Room Placement Test average distance error, $p < .01$.

Means and standard deviations for the untransformed data are presented in Table 9. The untransformed means are presented to allow easier interpretation and to facilitate data comparisons among groups with different levels of VE exposure. The significant differences in test performance between experts, and both groups of novices provides additional evidence that our selected measures are valid measures of configuration knowledge. Table 9 shows that experts perform better than novices with an aerial view, who in turn perform better than grounded novices. Close inspection of Table 9 reveals

Table 9

Untransformed Means and Standard Deviations of Configuration Knowledge Measures for Different VE Exposure Conditions

Levels of VE Exposure	Projective Convergence Test		Room Placement Test
	Distance Error	Heading Error*	Distance Error**
Grounded	19.91m (5.74)	57.80 degrees (19.52)	26.33m (22.38)
Aerial	16.31m (5.78)	45.00 degrees (19.19)	15.00m (12.80)
Expert	13.34m (4.29)	25.70 degrees (16.86)	5.59m (2.98)
Total	17.58m (6.00)	48.54 degrees (21.40)	18.99m (18.51)

* Significant difference between Aerial group and Expert group, p < .05.
** Significant difference between Aerial group and Expert group, p < .01.

that even the expert group's performance is far from perfect. Not only do our selected measures discriminate well among participants with varying amounts of configuration knowledge, but they also are sufficiently difficult that even "experts" do not achieve perfect performance.

The maximum Projective Convergence Test angular error is 180 degrees. The average angular error for the experts was 25.7 degrees. Hence, the angular error was roughly 16% of the maximum for the experts, 25% of the maximum for the aerial group, and 32% of the maximum for the grounded group. The maximum room placement distance averaged across rooms is 95.25 meters. The experts' Room Placement Test distance error was roughly 6% of the maximum error, whereas the aerial group was 16% of the maximum and the grounded group was 27% of the maximum. The performance trend among the various treatment groups is as might be expected. Furthermore, it appears that all groups have acquired some knowledge of the VE configuration.

Experiment 3: Retention of Spatial Knowledge

Background

Although spatial learning in VEs has been a hot research topic for the last decade, the research has focused primarily on the conditions under which spatial knowledge is acquired in VEs (Darken & Sibert, 1993; Satalich, 1995; Bliss et al., 1997; Ruddle et al., 1997) and whether or not this knowledge transfers to the real world (Witmer et al., 1996; Wilson et al., 1997, Waller, Hunt, & Knapp, 1998). Far less attention has been devoted to examining whether spatial knowledge learned in a VE is retained over time (Miller, et al., 1999). Miller et al. (1999) trained participants to navigate a route and to note the location of landmarks using either a VE, a map, or the real world. Two weeks later participants were tested on their ability to navigate the route and point to the landmarks they had learned. Half of them were tested in the aligned orientation (facing the same direction as in training) and half in the contra-aligned orientation (facing the opposite direction from their training orientation). On the retention test, VE-trained participants made significantly larger pointing errors than did participants in the other training groups, and the group differences were magnified for the contra-aligned condition.

In this experiment, we investigated how spatial knowledge changes over a one-week retention interval, and how the navigation aids affect retention of spatial skills. This provides additional information on the retention of spatial skills acquired in a VE and tested outside of the VE.

Method

Participants. After completing the first experiment, the novice participants were asked if they would be willing to complete a short test approximately one week later. Retention data was collected for 59 of the 64 participants. The retention group included 31 men and 28 women with an average age of 23.32 years.

Procedure. Approximately one week after completing the experiment, participants repeated the room placement test. Because participants did not know in advance what they would be required to do, it was unlikely that they made any special effort to memorize their room placement when tested initially or that any rehearsal occurred during the retention interval. The PC-based Room Placement Test required participants to click and drag labeled room cutouts to their correct positions on a map of the third floor. Whenever possible, the test was completed by the participants on their computer and returned via e-mail. Participants who did not have access to a computer either returned to the lab for testing or were tested off-site using a laptop PC. Five of the sixty-four original participants did not complete the retention test. A single measure of accuracy, the distance error between the judged room placement and the correct placement, was the dependent measure. Room placement time was not recorded for the retention test.

A repeated measures mixed model ANOVA was used to determine if there was a significant difference between the initial room placement scores obtained on the training day and room placement scores obtained one week after training and to determine the effects of the navigation aids on retention. The within subjects measure was testing occasion (initial versus retention) and the between subjects measures were perspective view, environment type, and orientation cue. To determine whether a particular navigation aid led to better retention, the testing occasion by navigation aids category interactions were examined.

Results and Discussion

Before analysis, the distance error scores were transformed using a power transformation. Over a one-week retention interval, performance on the spatial knowledge test declined significantly, $F(1,51) = 4.12$, $p < .05$. On the average, performance on the retention test was 3% less than on the initial room placement test. This represents a placement difference of approximately 0.74 meters. The correlation between scores on the initial test and retention test was $r(59) = .90$, $p < .001$, indicating high test-retest reliability for the room placement test.

The ANOVA revealed a significant main effect for viewing perspective on the retention test, $F(1,51) = 9.76$, $p < .01$. Participants who had access to an aerial view during training performed better on the retention test than those who did not. There was also a significant interaction between viewing perspective and environment type, $F(1,51) = 11.34$, $p < .01$. The nature of the interaction, shown in Figure 6, suggests that having an aerial view improved retention scores only for participants exposed to the standard environment. Participants who had both aerial views and the enhanced environment might have experienced information overload, and could not take advantage of the additional information provided by the aerial view.

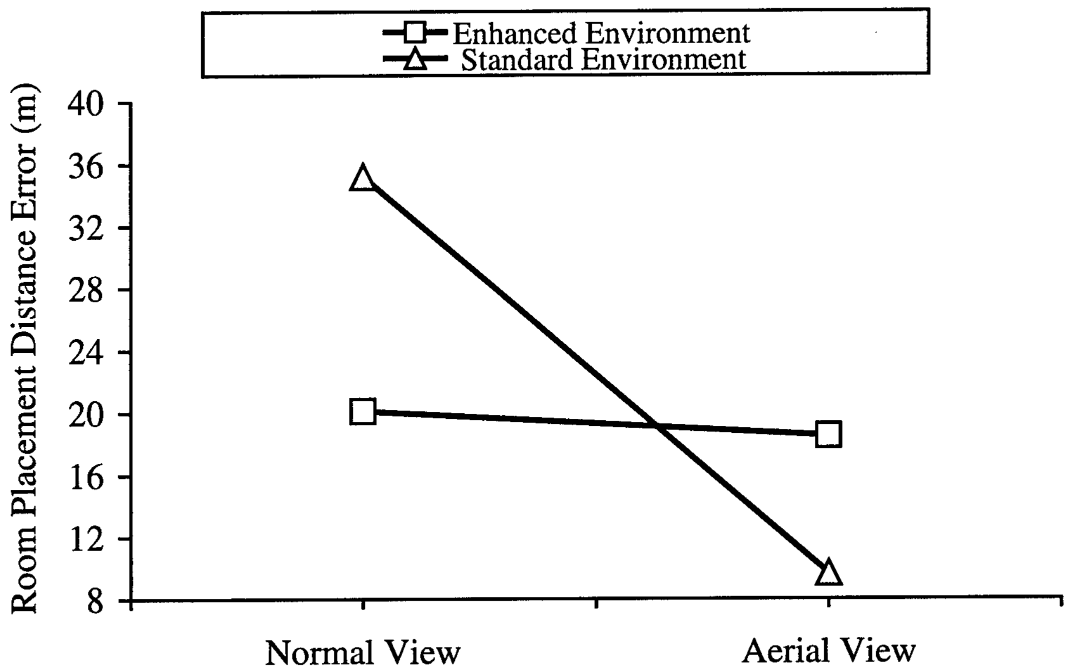

Figure 6. Interaction between viewing perspective and environment type.

There were no significant two-way interactions between any of the navigation aids and testing occasion. This suggests that none of the navigation aids differentially improved retention. Although the aerial group performed better on the retention test than the other groups, they also performed better on the initial test of spatial learning. Hence the aerial group retained the same proportion of what they had originally learned as the other groups. A significant three-way interaction between viewing perspective, orientation cue, and testing occasion was found, $F(1.51) = 4.50$, $p < .05$, but no reasonable interpretation of the interaction could be generated.

Conclusions

To summarize, research participants were required to learn the layout or configuration of one floor of an office building as portrayed in a VE. Because VEs typically do not completely and accurately represent the real world, the VE was enhanced with various navigation aids to compensate for the shortcomings inherent in VEs. These included orientation cues, a themed environment enhanced with sights and sounds and divided into segments, and the provision of an aerial perspective. The navigation aids were provided during the training, but were not available during configuration knowledge testing. Hence, the navigation aids could improve performance either during training, during testing, during both, or not at all. Navigation aids that improve spatial performance during training do not necessarily increase performance on spatial knowledge tests. If navigation aids are used as a crutch, no test performance gains are achieved. If used to structure and organize the environment, then real performance gains can be realized.

Orientation Cues

The orientation cues did not significantly affect performance either during the training phases or during testing. Contrary to expectation, providing a global orientation cue (i.e., flagpole) did not improve bearing estimates or the other configuration knowledge measures. Its lack of effectiveness may have been due to the inability of the participants to discriminate small changes in bearing from the sighting locations. Because of the long narrow building shape, the flagpole may have appeared to be approximately straight ahead regardless of the location of the sighting location.

Enhanced Environment Augmented with Images and Sounds

The enhanced environment helped participants find more destinations during the training phases, but had no effect on performance during testing. Enhanced images with sounds can improve performance of spatial tasks in a VE, but unless they are used to structure or organize the spatial information, they do no enhance performance in task situations where they are no longer present. In this research, participants apparently did not use the enhancements to structure the VE, despite instructions to do so. Their failure to use the enhancements was not because they could not remember the themes associated with each destination. On the Most Direct Route Test, with enhanced environment landmarks removed, participants trained in the enhanced environment recalled the themes associated with destinations almost 89% of the time. They recalled the names of the destinations only 86% of the time. Perhaps their workload was too great to devote the necessary cognitive resources to organize the environment into quadrants as instructed.

Aerial Perspective View

In contrast, the aerial view led to better spatial performance both during training and on tests of configuration knowledge. Participants were better able to structure and organize their environment if they had access to aerial views. It is not the amount of time spent in the aerial view that seems to determine how well the building configuration is learned; rather, it is how participants use their aerial time that affects spatial learning. If aerial time is used only to locate specific destinations, little configuration learning will occur, but if it is used to explore and organize the environment, then it will increase configuration learning. Supporting this conclusion was the finding that increased aerial time during free exploration was associated with better performance, whereas increased aerial time while searching for particular rooms was associated with poorer performance. Informal observations of participants' behavior also revealed that some participants used the aerial view solely to locate a targeted destination after they had failed to find it using the normal perspective view. Viewing height is important both for recognizing landmarks and for being able to view large portions of the environment simultaneously. In this experiment the 30-meter viewing height seemed to provide the best combination of landmark recognition and a large-scale view. With different environments, other viewing heights may be optimal.

Maps vs. an Aerial Perspective

No map condition was included in this experiment. Thus, the relative effectiveness of 2-D maps and aerial views was not assessed. The omission of the map condition was not an oversight; it was intentional and consistent with the purpose of the research. We purposely limited our research to looking at how the unique capabilities and features of VE might best be used to enhance the acquisition of configuration knowledge. Certainly, we could have electronically displayed a 2-D map of the VE, but that does not seem the best use of VE capabilities. Furthermore, the question would remain whether the electronic map was as good as a paper map. Numerous research studies have assessed the effectiveness of maps as tools for acquiring configuration knowledge (e.g., Thorndyke & Hayes-Roth,1982; Golledge, Doughtery, & Bell, 1995), and some have compared the effectiveness of map learning and VE learning without maps (Witmer et al., 1995; Satalich, 1995; Bliss et al., 1997; Ruddle et al., 1997). While the results have been mixed, it is clear that configuration knowledge can be acquired from maps and from VE without maps. The aerial views provided in this study have many of the attributes of a 2-D map, but also allow a direct view of landmarks and permit dynamic exploration of the environment from above.

Being provided an aerial perspective or having sufficient experience with an environment and ability to generate an aerial perspective seems the key to a highly evolved state of configuration knowledge. Several converging lines of evidence support this conclusion. Not only did novice participants with an aerial view perform better on our configuration knowledge measures, but they were less likely to reverse the placement of rooms in the environment and more likely to be among the top performers. Participants afforded an aerial view also performed more consistently across the various measures of configuration knowledge.

Disorientation

Reversals indicate an orientation problem. Knowing the location of rooms relative to one another is of little use if wayfinders head off in a direction opposite of the rooms' locations. Although the wayfinder may realize that he/she chose the wrong direction when the expected landmarks are not found, it still represents a serious error with obvious practical consequences. Therefore, we treated reversals as serious errors rather than treating them as artifacts that have no bearing on configuration knowledge. Providing an aerial view nearly eliminates reversals with only one participant who had an aerial view partially reversing the room positions.

Collisions may affect orientation in that participants may become disoriented following a collision. Widening hallways and doorways and other changes to the VE appeared to reduce the collision rate to one-fifth of that observed in previous research (Witmer et al., 1995). The lower collision rate in this study could also be the result of using a more natural interface to control movement than was used in the previous research. The walking interface in this study was easier to use than controlling movement by pressing buttons to move in the direction that you are facing. Although we

were successful in reducing the average collision rate, higher collision rates in this study were still associated with poorer performance. Providing local orientation cues did not result in further significant reductions in collision rate, probably because the collision rates were already low. The fact that the local orientation cues did not significantly reduce the rate of collisions explains in part why participants given orientation cues did not perform better on the configuration knowledge tests.

Simulator Sickness

The amount of simulator sickness in general was not related to measures of configuration knowledge. For those who completed the experiment, simulator sickness was not a determinant of performance. Of course it made the overall training less pleasant for affected individuals and probably reduced the amount of presence experienced in the VE. Its major effect was on those who could not complete the experiment. Although we assured these participants that it was not their fault that they were unable to continue the experiment, some of them seemed to feel bad that they could not finish the experiment. This was in addition to the unpleasant physical symptoms that they experienced. In this experiment one participant in five was not able to complete the experiment. This increased the time and effort required to conduct the experiment. An effective screening device for identifying those participants who will experience significant simulator sickness symptoms in VEs is badly needed. The simplest screening device would consist of a short questionnaire that could be used to identify susceptible individuals. The screening device specifically would need to predict simulator sickness susceptibility in VEs. Standard motion history sickness questions do not seem to be very predictive of VE simulator sickness. A more complex screening device that exposes potential trainees to a VE known to produce symptoms for 5-10 minutes could be used to identify susceptible individuals before their symptoms reach uncomfortable levels.

A Preferred Measure of Configuration Knowledge

Of the tests measuring configuration knowledge in this experiment, the Room Placement Test is likely the best measure of an individual's capability to generate an aerial view. Assuming that being able to generate an aerial view represents a more evolved or advanced stage of configuration knowledge, then this test is a useful indicator of advanced configuration knowledge. Those measures that better discriminate among the novice and expert groups might be considered to be better measures of configuration knowledge. Room placement distance error was the best discriminator between experts, learners with an aerial view, and learners with a normal view. Room placement distance error was also sensitive to retention losses. This is not to say that other measures are not useful. Projective convergence angular and distance errors were also effective discriminators between expert and novice performers. Projective convergence measures might even be preferred for assessing performance in the earlier stages of configuration knowledge before an aerial perspective has fully developed. Although performance on projective convergence measures may benefit from having an aerial perspective, generating an aerial perspective is not necessary for pointing and estimating distance.

Training Transfer from the Training to the Testing Situation

The Room Placement Test could be considered a defacto test of transfer from VE to the real world. It was conducted outside of the VE and required participants to construct a map like one that they might construct for use in the real world environment. If participants have sufficient spatial knowledge to construct a map, they likely also have sufficient spatial knowledge of the environment to apply it in the real world environment. In this experiment, experts and participants provided an aerial view were more likely to have this knowledge.

It is important to emphasize that providing navigation aids is not always sufficient. The user must be capable of using the aid in the particular task situation. For example, if the task workload is too great, the aid may even decrease learning and performance. The user must choose to use the aid as it was intended to be used rather than as a performance crutch. It appears that our research participants did not segment the environment according to the themes provided, and certainly did not use the themed quadrants in locating destinations during testing. Instead they used the themed objects and associated sounds as landmarks. While this strategy helped to locate the destinations during training, it was useless when these landmarks were removed for testing purposes. Similarly participants who used the aerial view as a crutch just to locate particular destinations during destination search training did not perform as well as participants who used the aerial view to learn the layout of the environment.

Retention

Performance on the retention test was also affected by having an aerial view, at least for the participants exposed to the standard environment. An aerial view improved the acquisition of configuration knowledge and allowed excellent retention of that knowledge. Although performance on the configuration knowledge test was significantly less for retention than for initial testing, the differences in performance on the two tests were small, averaging less than 1 meter. This indicates that much of what was learned during training in the VE was retained over a one-week retention interval. Apparently, the decay rates for configuration knowledge acquired in a VE are low. While the aerial view led to significantly better performance on the retention test, it did not result in less forgetting than did any of the other navigation aids.

Predicting Configuration Knowledge

Although the primary objective of this research was not to generate a predictive model, we have identified some promising predictors of configuration knowledge. These include spatial ability as measured by the Cube Comparisons Test, sense of direction, gender, interface proficiency (collisions and movement speed), the number of destinations found and identified during training, and confidence in using computers. When 14 different predictors were entered into a regression model, the combined predictors accounted for an average of 46% of the variance across the six configuration knowledge measures. When these predictors were grouped conceptually and entered into

regression models, each of the variable groups reliably predicted measures of configuration knowledge. Wayfinding variables measured during training reliably predicted all six of the configuration knowledge measures. The two variable groups reflecting individual differences, interface proficiency and personal traits, were also reliable predictors of most of the configuration knowledge measures. The variable group that included the navigation aids predicted only two of the six measures.

In predicting configuration knowledge it is important to note that many of the predictors are themselves intercorrelated. Thus many of the predictors may account for the common variance in the configuration knowledge measures. In this research much of the unique variance in configuration knowledge measures was accounted for by personal traits, followed closely by navigation aids. Interface proficiency also accounted for some unique variance but only for the Most Direct Route measures. This is understandable since the distance covered and total time required to locate destinations would likely be affected by the proficiency of movement through the VE. Perhaps the most surprising result is that personal traits generally accounted for more variance in configuration knowledge measures than did navigation aids. This finding is indicative of the magnitude of individual differences in spatial skills and in particular the large individual differences in the ability to acquire spatial knowledge in VEs.

Implications of Research Findings

This research has shown that configuration knowledge can be acquired in a relatively complex VE in an efficient manner without relying on external training aids (e.g., maps, written directions). Furthermore, this knowledge can be retained over a one-week retention interval with negligible retention loss. This is especially important for mission rehearsal, where knowledge of enemy areas or facilities needs to be retained for the period of time between mission rehearsal and mission execution. Navigation aids can improve spatial knowledge acquisition, but the manner in which they are used determines their effectiveness. Trainers must ensure that soldiers use the navigation aids to structure and organize the VE to improve acquisition and retention. Trainers may also need to limit the number of aids available at any given time to preclude information overload and allow the soldiers to derive maximum benefit from the aid. Although navigation aids can improve spatial performance, individual differences in spatial ability and proficiency in using the VE interface exert considerable influence on the spatial knowledge acquired in a VE. Trainers may need to allow some individuals an extended period of practice in with the VE interface devices before using VE for mission rehearsal. This additional practice may also help identify those individuals who are highly susceptible to simulator sickness and allow time for those who are mildly susceptible to adapt to the VE.

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Appendix A. Demographics Questionnaire

ID______________

Date_____________

Please fill in the blank or circle the appropriate response.

1. What is your age? _____ years
   (age)

2. What is your gender? female male
   (sex) 1 2

3. Are you currently in your usual state of good fitness? yes no
   (fitness) 1 0

4. How many hours sleep did you get last night? _____ hours
   (sleep)

4a. Was it sufficient? yes no
   (slepsuff) 1 0

5. Indicate all medications/substances you have used in the past 24 hours:
   (medsubs)
   CIRCLE ALL THAT APPLY

   0 - none

   1 - sedatives or tranquilizers

   2 - aspirin, Tylenol, other analgesics

   3 - anti-histamines

   4 - decongestants

   5 - other (please list: ____

6. Have you ever experienced motion or carsickness? yes no
   (motsick) 1 0

7. How susceptible to motion or carsickness do you feel you are?
   (motsscpt)

0	1	2	3	4	5	6	7
not susceptible	very mildly			average			very highly

8. Do you have a good sense of direction? yes no
   (dirsnse) 1 0

9. How many hours per week do you use computers? _____ hours per week
(compuse)

10. My level of confidence in using computers is
(compcon)

1	2	3	4	5
low		average		high

11. I enjoy playing video games (home or arcade).
(vid_joy)

1	2	3	4	5
disagree		unsure		agree

12. I am _____ at playing video games.
(vid_con)

1	2	3	4	5
bad		average		good

13. How many hours per week do you play video games? _____ hours per week
(vidplay)

14. How many times in the last year have you experienced a virtual reality game or entertainment? (vr_exp)

0 1 2 3 4 5 6 7 8 9 10 11 12+

15. Do you have a history of epilepsy or seizures? yes no
(epilepsy) 1 0

16. Do you have normal or corrected to normal 20/20 vision? yes no
(normvis) 1 0

17. Are you color blind? yes no
(colrblnd) 1 0

Appendix B. Transforms for Configuration Knowledge Measures

Most Direct Route Test Measures:

Transformed Distance Error = ABS((Distance Error)$^{.33}$)

Transformed Search Time = 1/(Search Time)$^{.65}$

Room Placement Test Measures:

Transformed Distance Error = 1/(Distance Error)$^{.34}$

Transformed Placement Time = 1/(Placement Time)$^{.65}$

Projective Convergence Test Measures

Transformed Distance Error = 1/(Distance Error)$^{.25}$

Heading Error Required no Transformation

Appendix C. Untransformed Means and Standard Deviations of Performance Measures during Training and Testing Phases

Table C-1.

Untransformed means and standard deviations for training phase performance measures as a function of type of navigation aid

Navigation Aid Provided	Rooms Found - Exploration Phase	Rooms Found – Search Phase	Search Time – Search Phase	Distance Traveled – Search Phase
Normal View	4.13 (1.43)	4.59 (1.29)	513.61 (217.97)	489.22 (194.51)
Aerial View	4.38 (1.24)	5.53 (.80)	417.83 (195.27)	366.41 (133.89)
No Orientation Cues	4.66 (1.15)	5.13 (1.07)	452.98 (207.01)	425.98 (172.43)
Orientation Cues	3.84 (1.39)	5.00 (1.27)	476.56 (216.82)	427.67 (182.83)
Standard Environment	3.91 (1.23)	4.78 (1.26)	472.71 (195.33)	438.45 (168.36)
Enhanced Environment	4.59 (1.36)	5.34 (1.00)	457.45 (227.43)	415.59 (185.75)

Table C-2.

Untransformed means and standard deviations for configuration knowledge test measures as a function of type of navigation aid

Navigation Aid Provided	Most Direct Route Test		Room Placement Test		Projective Convergence Test	
	Distance Error (m)	Search Time (sec)	Distance Error (m)	Placement Time (sec)	Heading Error (deg)	Distance Error (m)
Normal View	23.99 (21.38)	75.77 (26.81)	26.33 (22.31)	115.19 (90.61)	57.8 (19.52)	19.91 (5.74)
Aerial View	23.13 (29.29)	76.56 (36.34)	15.08 (12.86)	92.25 (38.10)	44.99 (19.19)	16.31 (5.78)
No Orientation Cues	28.44 (31.86)	78.89 (33.97)	22.71 (19.50)	93.16 (63.03)	53.52 (19.96)	18.02 (5.15)
Orientation Cues	18.68 (15.85)	73.44 (29.50)	18.69 (18.49)	114.28 (75.70)	49.27 (20.64)	18.20 (6.83)
Standard Environment	19.33 (17.36)	69.29 (24.64)	21.11 (20.90)	103.47 (76.64)	51.58 (21.45)	18.77 (7.32)
Enhanced Environment	27.79 (31.26)	83.04 (36.54)	20.30 (20.09)	103.97 (63.72)	51.20 (20.25)	17.45 (4.31)